Enabling Commercial PEM Fuel Cells With Breakthrough Lifetime Improvements

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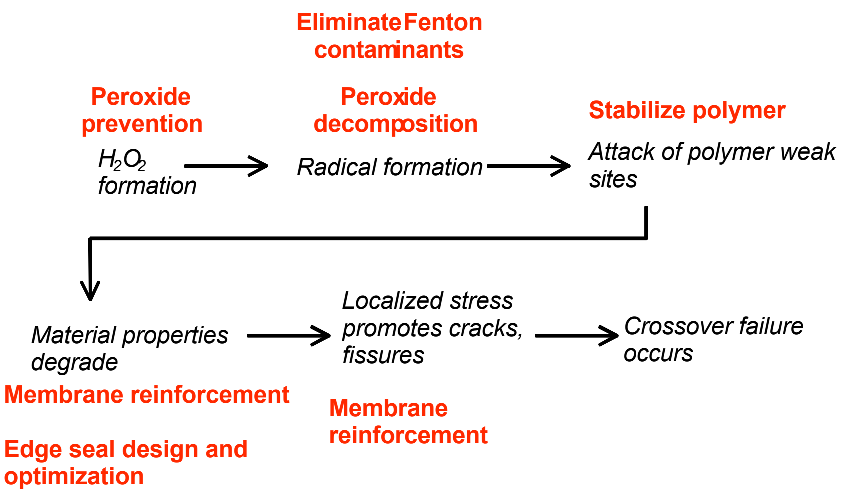
Project Overview / Objectives

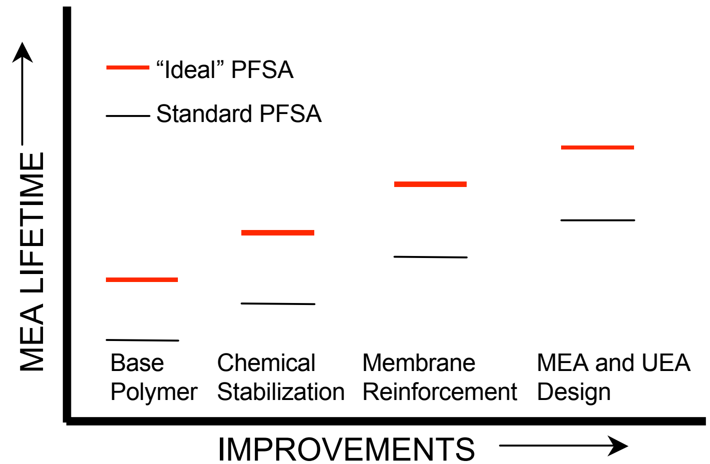
Road to Failure

Through both experiments and modeling, we have developed an understanding of potential mechanisms than can lead to membrane failure

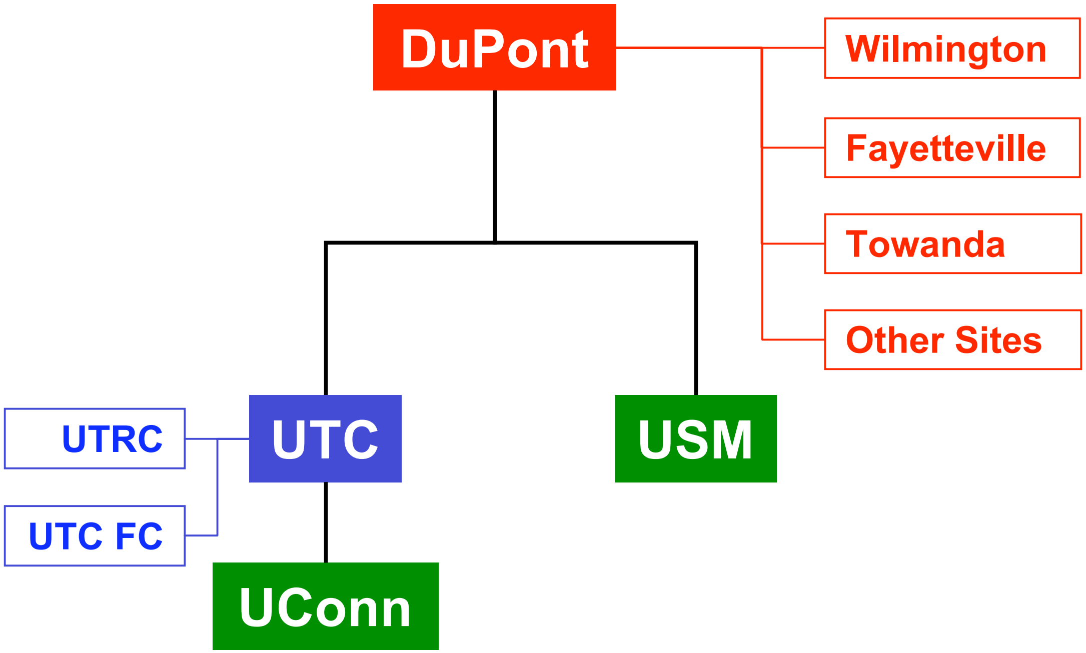


Road to Success

Individually, each of these strategies improves membrane durability. This program will optimize each and incorporate them, in toto, *into fuel cell products.*



Team--Interactions & Collaborations



Laying the groundwork….

The core DuPont / UTC team has been jointly investigating MEA durability improvement techniques for over 3 years. Consequently, while still in the first year of this program, we have already demonstrated the feasibility of several durability enhancement strategies.

This team encompasses all aspects of the supply chain from raw materials to power plants. Our tight integration allows quick, reliable validation of any durability enhancement strategies.

Raw materials

↓

Nafion® membranes

↓

DuPont Fuel Cells MEAs

↓

UTC Cell Stack Assemblies

↓

UTC Power Plants

Approach

Task 1. Materials Synthesis

Task 2. Accelerated Aging Tests

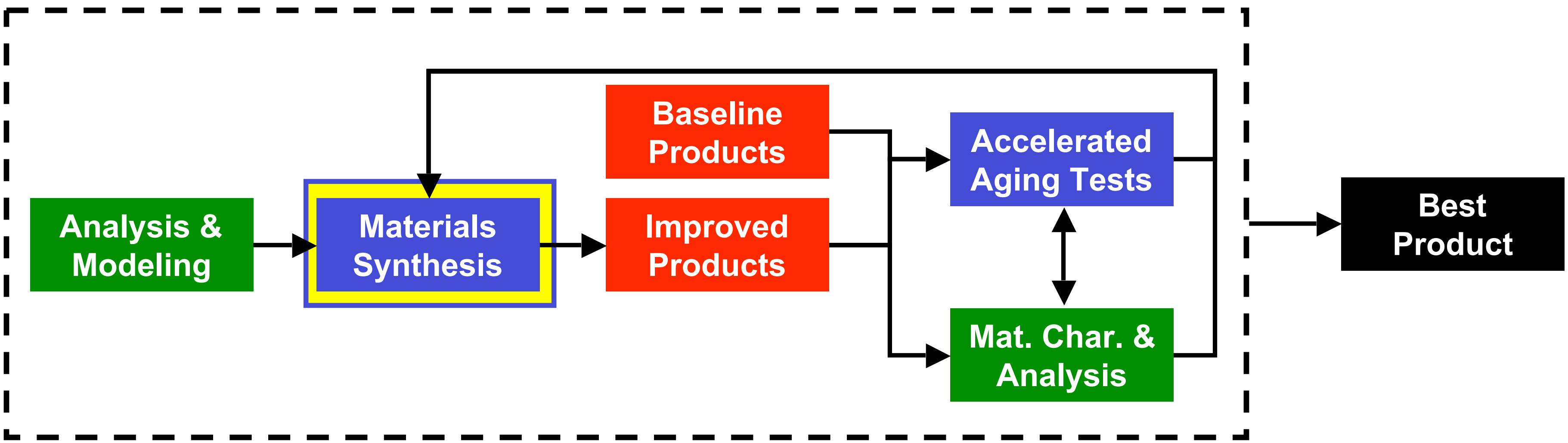
Task 3. Analysis and Modeling

Task 4. Stack Testing

Task 5. Materials Char. and Analysis

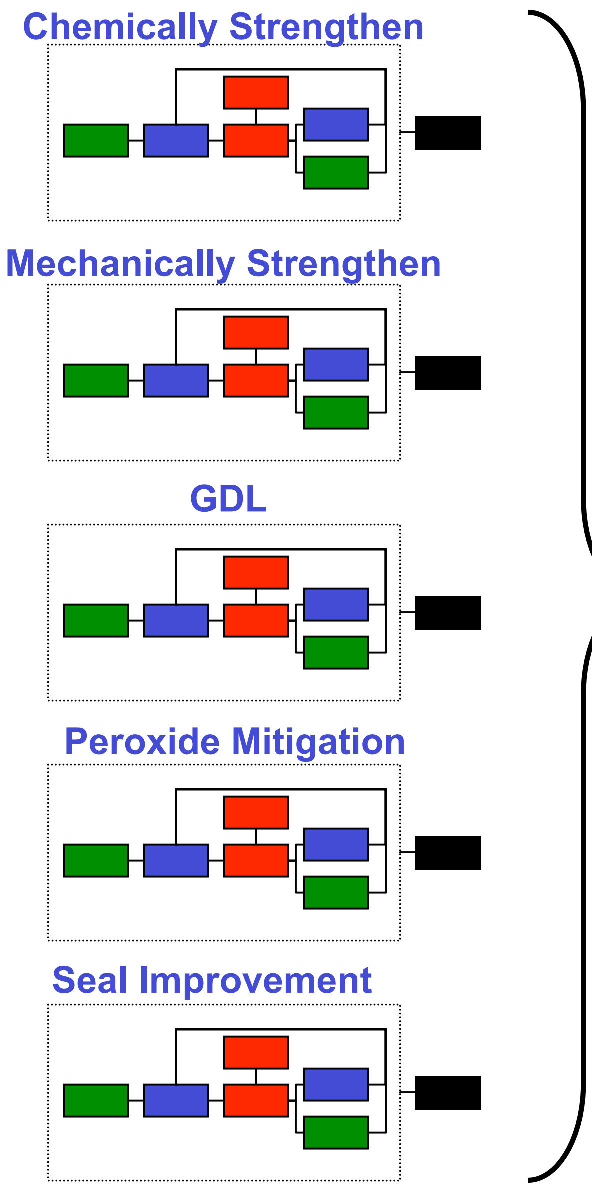
Task 6. Cost Analysis

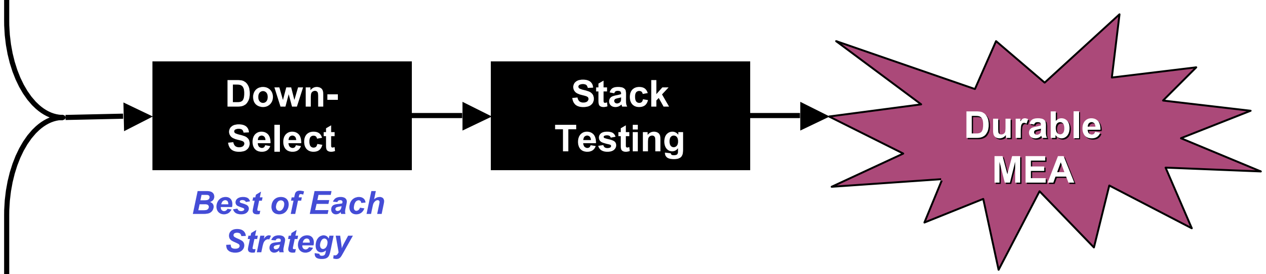
Process Map for a Given Potential Improvement (*e.g.* Mechanical Reinforcement)



Approach

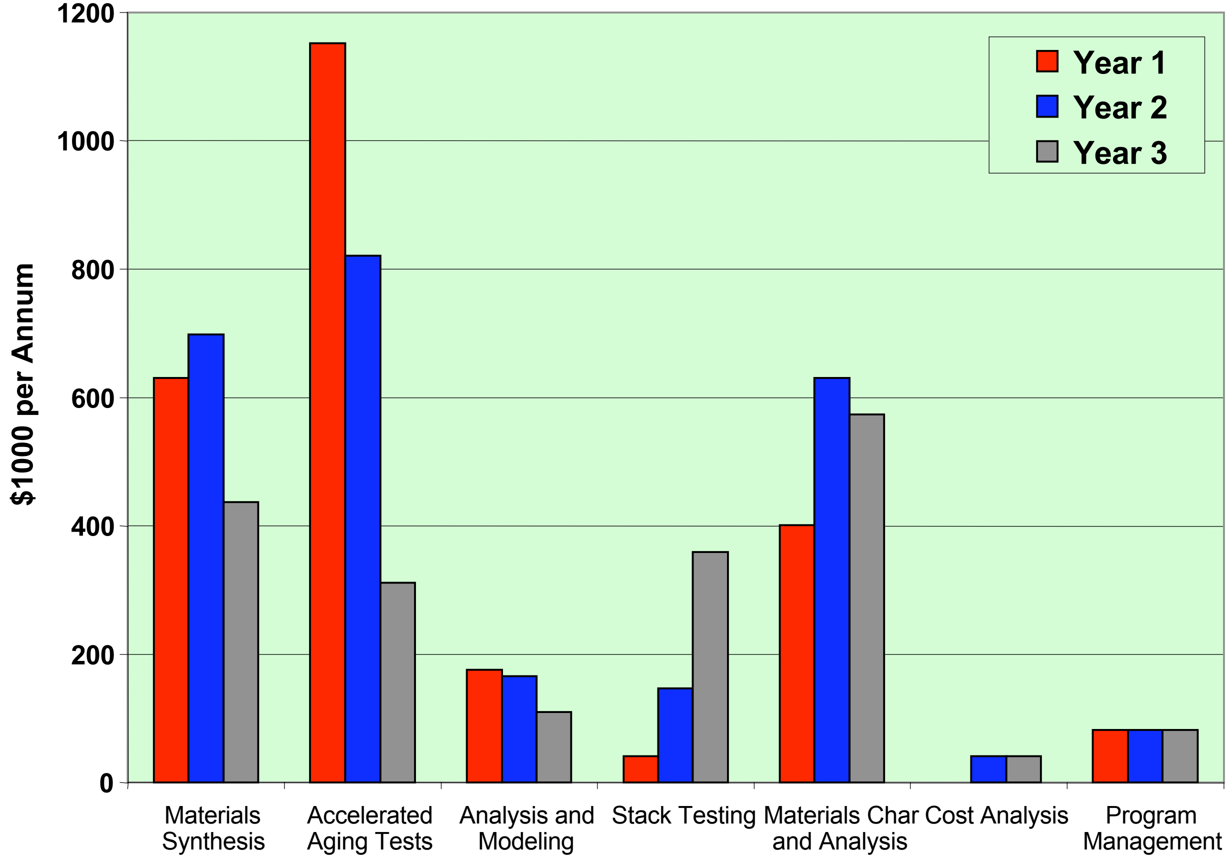
We are optimizing several proven durability enhancements in parallel. At various down-select points, we shall incorporate the best of each mitigation strategy into fuel cell stacks to validate improvements.





Budget Projections

1000 $	$Total	$DOE	$DuPont
FY 2004	2905	2324	581
FY 2005	2958	2367	592
FY 2006	2928	2343	586
Total	8792	7033	1758



Technical Barriers and Targets

- **DOE Technical Barriers for Fuel Cell Components**
  - O. Stack Material and Manufacturing Cost
  - P. Durability

- **DOE Technical Target for Fuel Cell Stack System for 2010**
  - Cost not greater than current Nafion® projections
  - Durability > 40,000 hours (stationary), 5000 hours (auto)

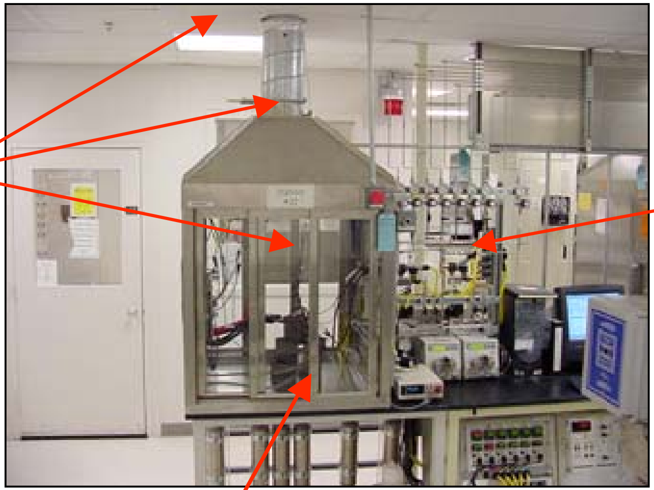
DuPont Fuel Cells
". . . powered by DuPont"

Safety is a DuPont Core Competency

- Working and living safely is pervasive throughout DuPont culture
- Consequently, all fabrication and testing is subject to a rigorous Safety, Health, and Environment review before commencement of any work. Any safety incidents are thoroughly investigated to capture learnings.
- Our safety record validates the effectiveness of our acute attention to detail

DuPont Fuel Cells has never had a hydrogen-related safety incident. We attribute this to careful planning of both operating procedures and facilities installation.

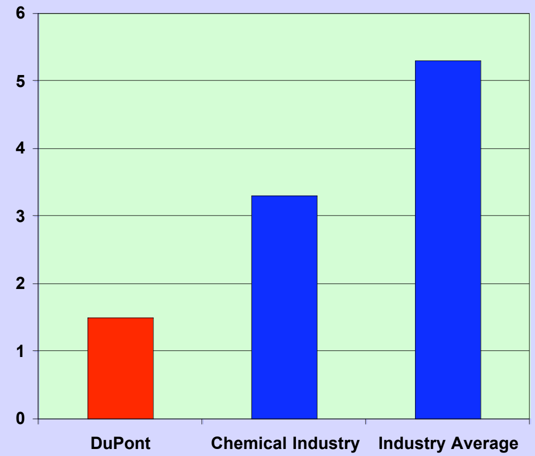
H_2 Detector



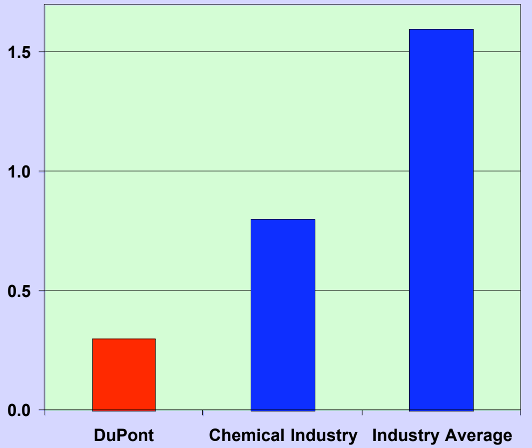
"Open Space" around test station plumbing

All fuel cell hardware contained within ventilated enclosure

Total Reportable Incidents
(per 100 employees)



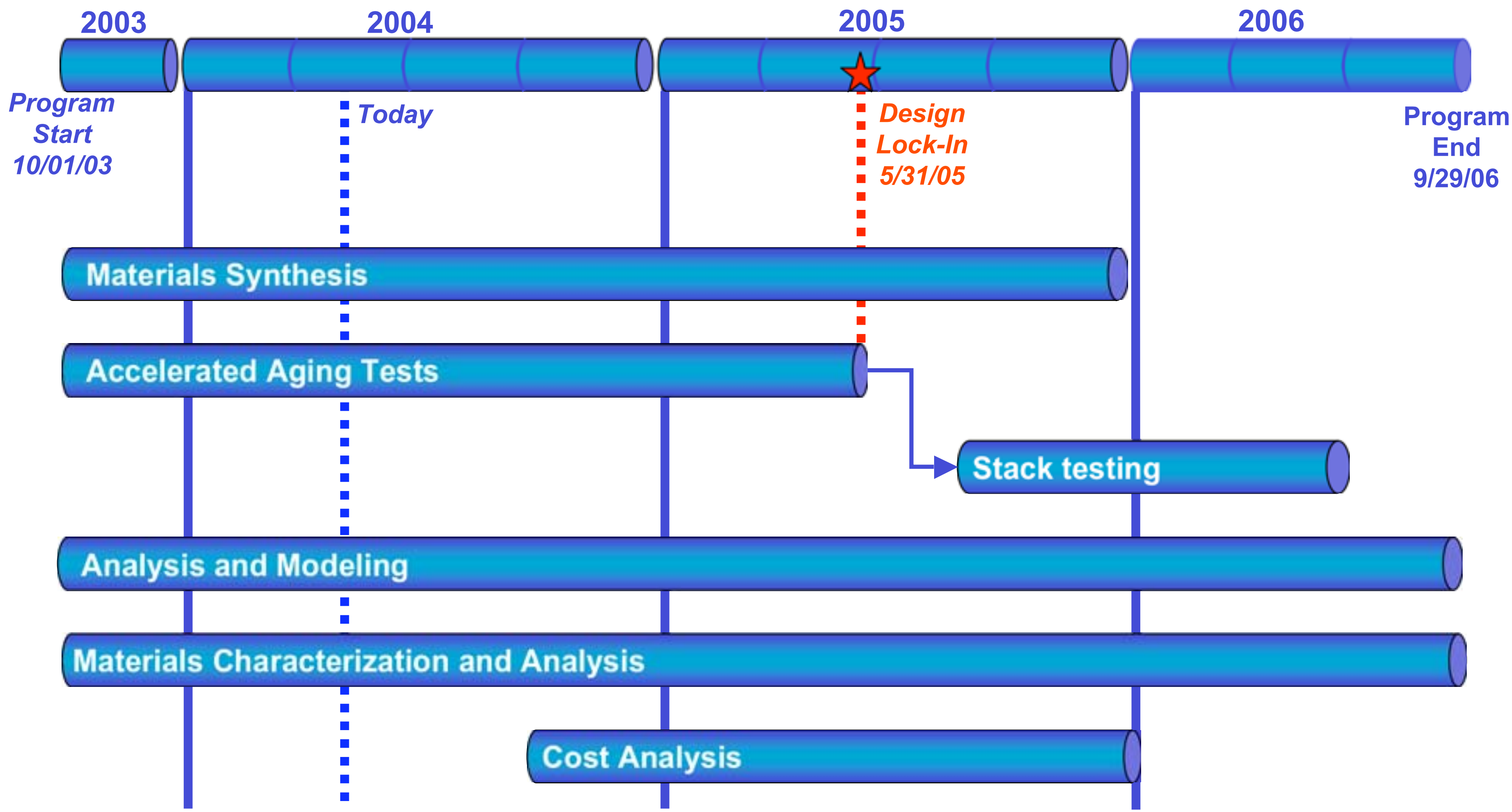
Lost Work Cases
(per 100 employees)



Source: U.S. Bureau of Labor Statistics, 2002 Data--Injuries and Illnesses

The miracles of science

Project Schedule



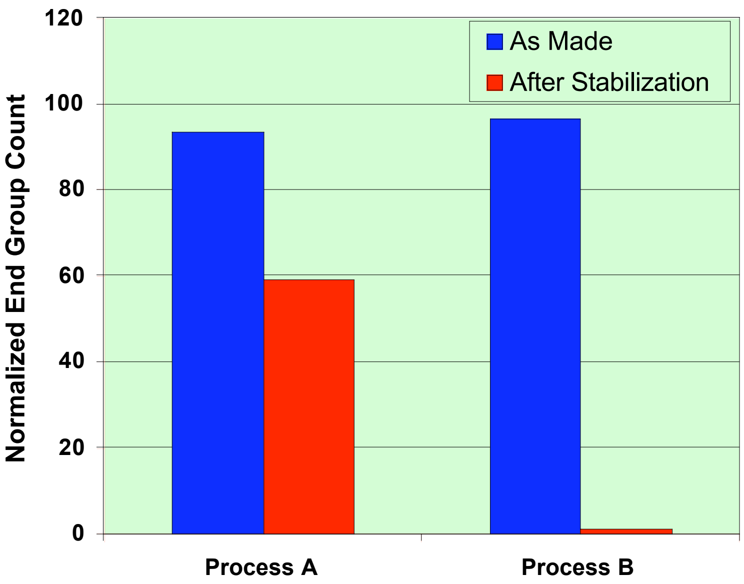
Resistance to Peroxide Attack

GOAL: Design membrane that is completely resistant to chemical attack

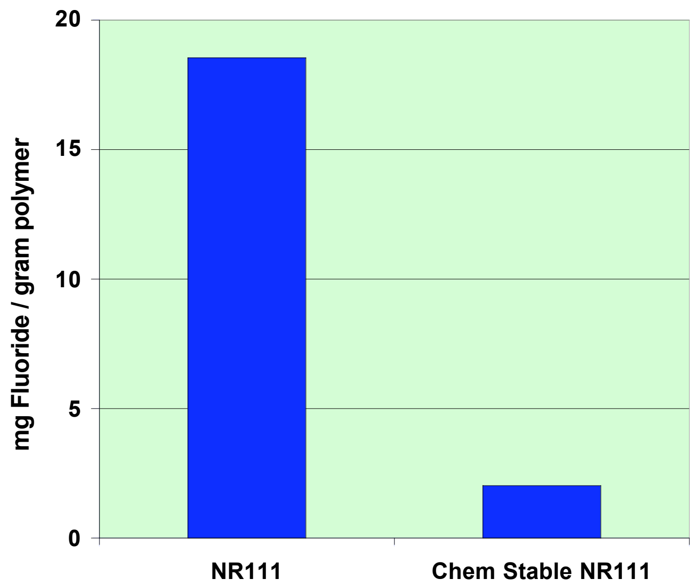
We have demonstrated that polymer chain end-groups are susceptible to peroxy radicals

- **Correlation exists between polymer degradation and number of polymer chain end groups**
- **Reduction of end-groups shown to improve chemical stability**

Processing conditions reduce undesirable end group count to non-detect quantities



Fenton's Test proves that materials with reduced undesirable end groups exhibit increased resistance to chemical attack



Increasing Mechanical Stability

Desirable Membrane Properties:

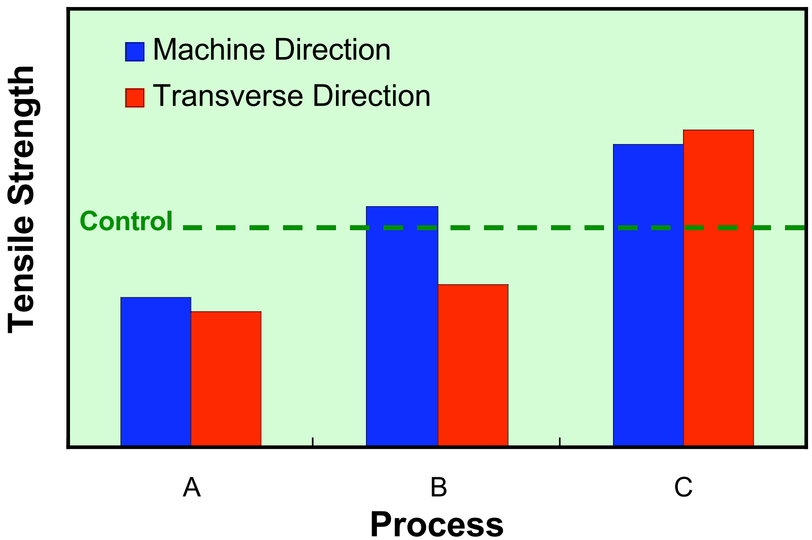
- **Increased Tensile Strength (>100% improvement over current product NR111)**
- **Isotropic Properties (tensile strength, tensile modulus, coefficient of moisture expansion)**

We have made significant progress in membrane properties (mechanical strength and isotropy) through:

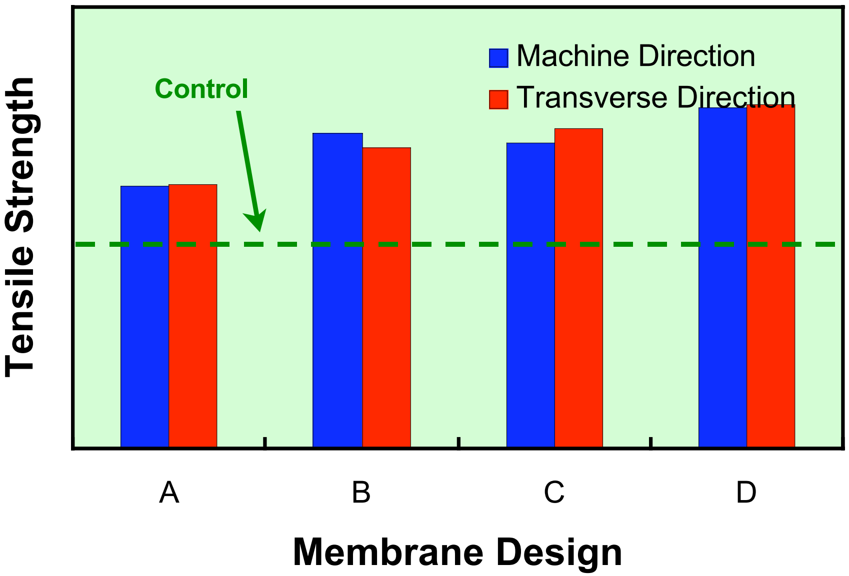
- **Process design**
- **Material design**

We are establishing correlation between these properties and durability
We will improve tensile strength by an additional 50% by 3Q'04
We will optimize our materials to minimize CME below 5%.

Improvements in Tensile Strength Through Process Conditions



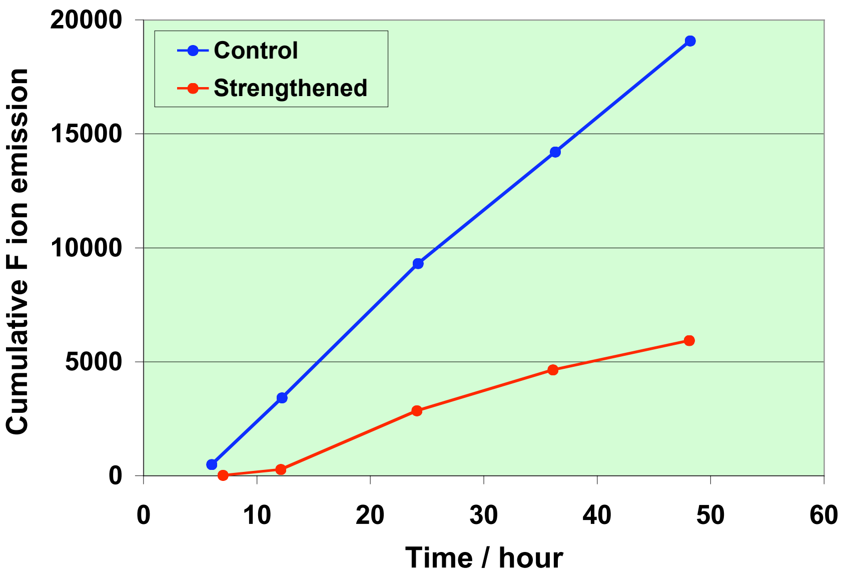
Improvements in Tensile Strength Through Membrane Design



Accelerated Test Validation

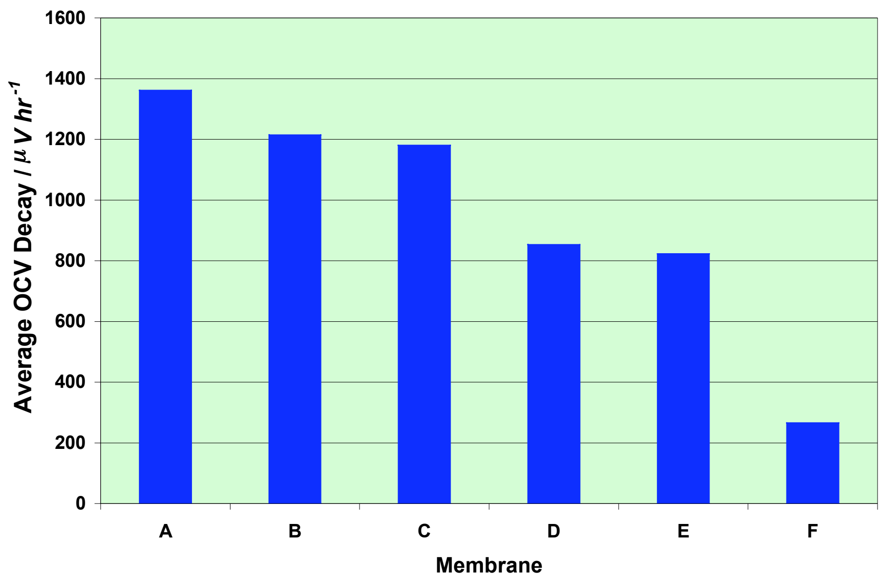
Accelerated chemical degradation

- MEA is held *in situ* at conditions known to be conducive to H_2O_2 formation
- Effluent water is measured for fluoride ions
- As expected, strengthened membranes give lower fluoride emission rates



Accelerated mechanical degradation

- We have confirmed that OCV is indicator of membrane integrity
- Test developed to reproducibly accelerate membrane degradation
- As expected, strengthened membranes give lower OCV decay rates



Peroxide Mitigation Technology

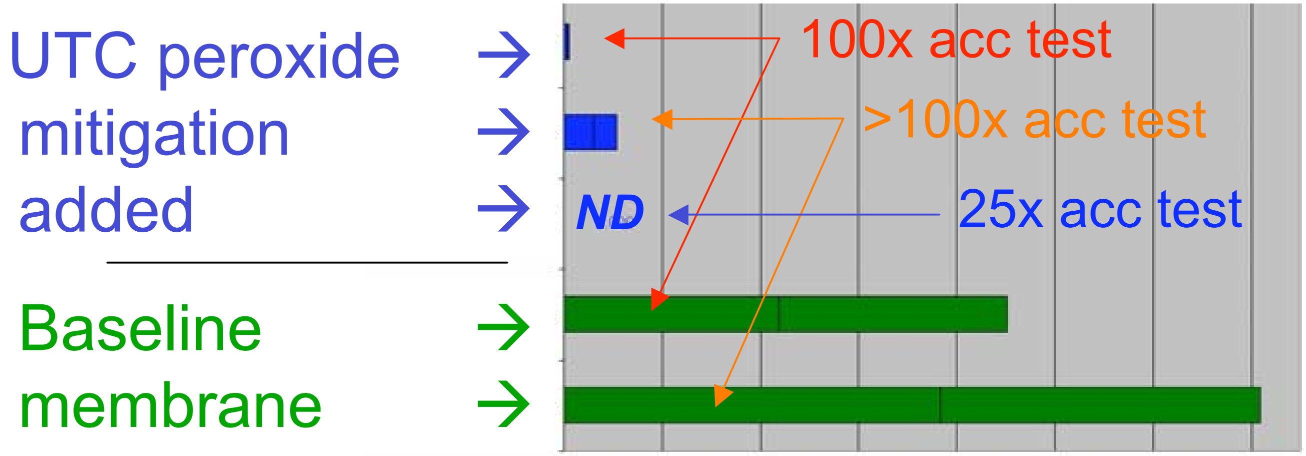
UTC Peroxide Mitigation Design Strategy:

- Identify mechanisms of peroxide-engendered attack of the PEM membrane
- Use physics-based modeling to design mechanism-based mitigation strategies

Progress:

- Designed and optimized mitigation strategies using physics-based models
- Qualified in accelerated tests (sub-scale) w/ fluoride emission rate (FER) / membrane leak current:
  - Multiple 200 hr highly accelerated tests (>100x)
  - Attained 3000 hrs in ~25x accelerated tests with no membrane failure

In 25-100x accelerated tests, UTC mitigation strategies :
- Reduced fluoride emission rates (FER) by 10-100x
- to FER levels comparable to membrane lasting 16,000 hrs in non-accelerated tests



Relative fluoride emission rate

Mitigation Technology Optimization

Issue – Peroxide mitigation strategies have some impact on cost, performance

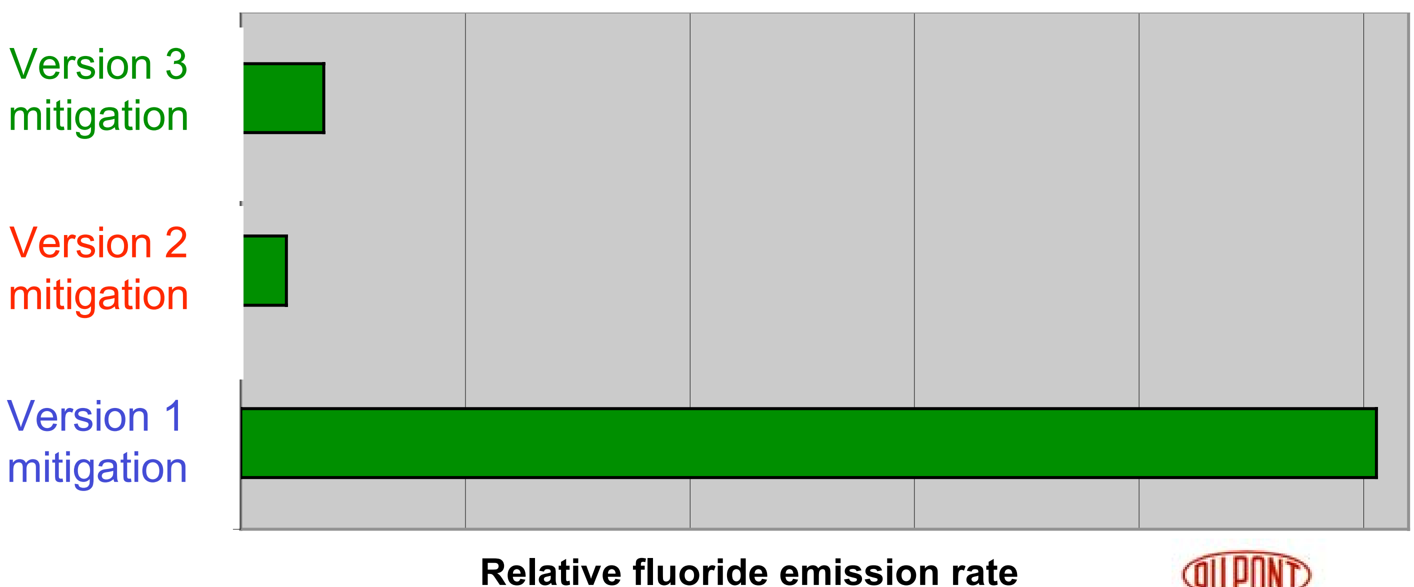
UTC Strategy:

- **Identify improved mitigation structures to reduce impact on cost, performance**
- **Use physics-based modeling to optimize these structures before testing**

Progress:

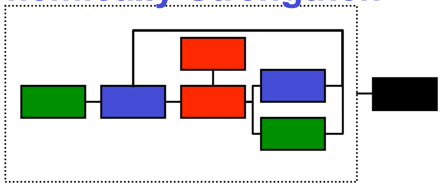
- **Have experimentally demonstrated improved structures:**
  - **Version 1 used in previous slide**
  - **Version 2 has 50% less impact on cost, performance**
  - **Version 3 has >50% impact on cost**
  - **Versions 2&3 actually better despite lower impacts on cost, performance**

Future mitigation structures for 40,000 hr. life attainable with negligible cost & performance impact



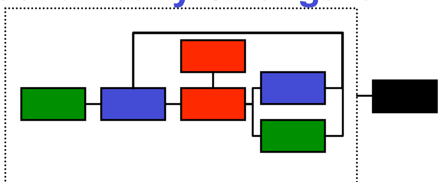
Future Work

Chemically Strengthen



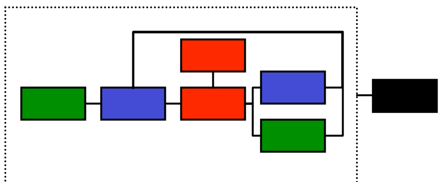
- Study end group *vs.* membrane decomposition correlation
- Correlate *ex situ* test data to *in situ* test data
- Optimize chemically stabilized membrane

Mechanically Strengthen



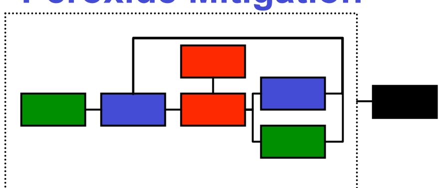
- Optimize composition and processing conditions
- Evaluate under both accelerated and real-time testing conditions

GDL



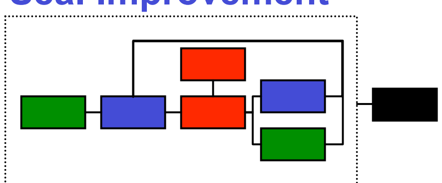
- Continue durable GDL scouting
- Study affects of PTFE coating on macroporous layer durability

Peroxide Mitigation



- Evaluate under long-term 10x accelerated conditions in full-size parts and short stacks
- Continue structural improvements to lower cost, increase performance
- Investigate other potential degradation mechanisms

Seal Improvement



- Physics-based modeling for durability-based seal design
- Continue seal materials evaluation